International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249–6890; ISSN (E): 2249–8001
Vol. 11, Issue 5, Oct 2021, 231–246

ENERGY SECURITY: INVESTIGATING GEOTHERMAL HEAT SINKS FOR AIR CONDITIONING SYSTEMS AT AIRPORTS IN SOUTH AFRICA – A TECHNOECONOMIC ASSESSMENT

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ABSTRACT

The use of renewable energy instead of carbon intensive fossil fuels for energy to reduce our ever-increasing global carbon emissions that is accelerating climate change is now a common trend. The uptake of renewable energy, however, needs to increase exponentially if the countries of the world are to follow the reduction by 1.5 or 2 pathways as per the Paris Agreement to arrest climate change. Air conditioning is a significant energy user in buildings especially in warmer countries like South Africa and accounts for a significant amount of electricity being consumed within a year. Air conditioning systems that adopt water cooled chillers also consume significant amounts of water to make up in losses due to evaporation. In their 20 to 25-year lifespan air conditioning systems place a great burden on the environment. This cost to the environment also costs the owners of the air conditioning systems. Finding a way to save on the amount of water and electricity used for cooling towers of air conditioning systems so that the natural environment cools the chillers without huge costs for electricity to drive fans and water to make up for evaporative losses, is a financial win for owners of air conditioning systems as well as a contribution to the environment by way of reduction in carbon emissions. This paper investigates the adoption of geothermal heat sinks to serve as a replacement to cooling towers at an airport environment in South Africa, showing the technical and economic assessment (technoeconomic assessment) based on the geothermal heat sink installation at Hotel Verde in the Western Cape of South Africa.

KEYWORDS: Renewable Energy, Geothermal Heat Sink, Green Air Conditioning, Energy Conservation for Air Conditioning Systems & Water Saving for Air Conditioning Systems

Received: Sep 19, 2021; **Accepted**: Oct 09, 2021; **Published**: Oct 14, 2021; **Paper Id**.: IJMPERDOCT202116

Original Article

1. INTRODUCTION

Reducing the need for large amounts of electricity to meet the requirements of air conditioning and saving on potable water by the adoption of geothermal heat sinks is a major operational cost saving and carbon footprint offset. Using geothermal energy to serve as a heat sink saves on the cost of maintenance and reduces the carbon footprint of a site.

In geothermal heat sink systems, electricity is required to run circulation pumps, but this is minimal due to the hydraulic design of the system. Water is used in a closed loop system so water consumption is negligible. With a lifespan of about 50 years, such a system is an ideal investment due to its low cost of maintenance. The use of geothermal heat sinks is favourable with a ground temperature of 20 ℃ at a depth below the seasonal layer of the ground which is about 8 m.

This study performed over the financial year 2018/2019 (April 2018 – March 2019) covers technology description, identification of technology type, typical components constituting the technology, dynamics around

their coexistence within the operating environment, assessment of technology maturity, cost benefit analysis that looks at the investment required, energy and water saved, feasibility indicators of the investment and a sensitivity analysis.

This technology is targeted at this stage for the Cape Town International Airport (CTIA) which is owned and operated by Airports Company South Africa (ACSA), however, with time and familiarity with the technology, the intention is to adopt it across more airports in South Africa. The geothermal heat sink technology being scalable and modular in design makes an attractive replacement for air conditioning cooling towers across the airport group. In terms of reduction of the airports' carbon footprint, air conditioning can contribute 10 % to 30 % of the airports' energy consumption and cooling towers can contribute 3 % to 10 % of the total energy consumption of an airport. Historically, cooling towers have proven to be a challenge for ACSA in certain airports due to the cost of maintenance and water (especially in water scarce regions).

Airports Company South Africa is South Africa's airport authority, owning and operating nine airports in South Africa, namely, O R Tambo International Airport (Kempton Park, Gauteng), Cape Town International Airport (Western Cape), King Shaka International Airport (Durban, KwaZulu-Natal), Port Elizabeth International Airport (Eastern Cape), East London Airport (Eastern Cape), Bram Fischer International Airport (Bloemfontein, Free State), George Airport (Eastern Cape), Upington International Airport (Northern Cape) and Kimberley Airport (Northern Cape).

The key parameters for the geothermal heat sink technology to work are:

- A ground temperature profile of 20 °C below the seasonal layer (about 8 m to10 m) of the soil surface.
- Available and accessible ground (soil) space for a geothermal heat exchanger loop installation; a horizontal or vertical loop can be employed based on the flexibility and availability of the space.

The key criteria for geothermal heat sink technology to be adopted at airports in South Africa are:

- Must have the potential to reduce the airport's carbon footprint.
- Must make financial sense to the business.
- Must be a reliable and effective heat sink with a high-capacity factor that is able to sustain the airport's HVAC heat sink requirements.
- Risks should be acceptable.
- Should have a local footprint for technical support with acceptable response times to support operations.

2. DESCRIPTION OF THE TECHNOLOGY

Conventional geothermal energy technologies extract ground heat occurring as a result of seismic activity for steam generation that either turns the shaft of an electrical generator, producing electricity, or that is used directly for space heating in winter (Figure. 1). This sort of geothermal energy generation is popular in the United States of America and in countries where it often snows during the winter months. South Africa has geothermal energy potential as well, but this has not been tapped into (Figure. 2).

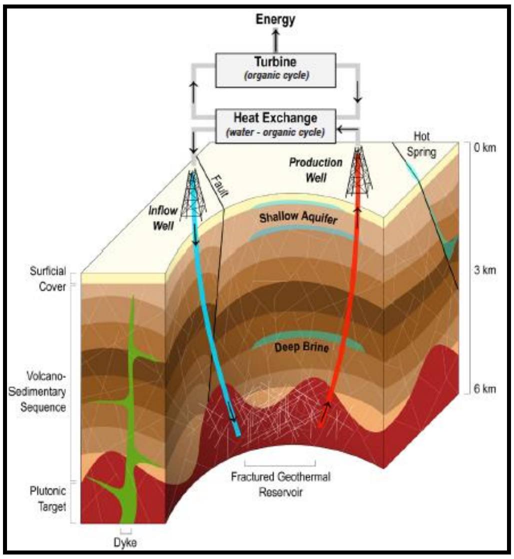

Figure 1: Conventional Geothermal Energy Extraction Generating Electricity [1].

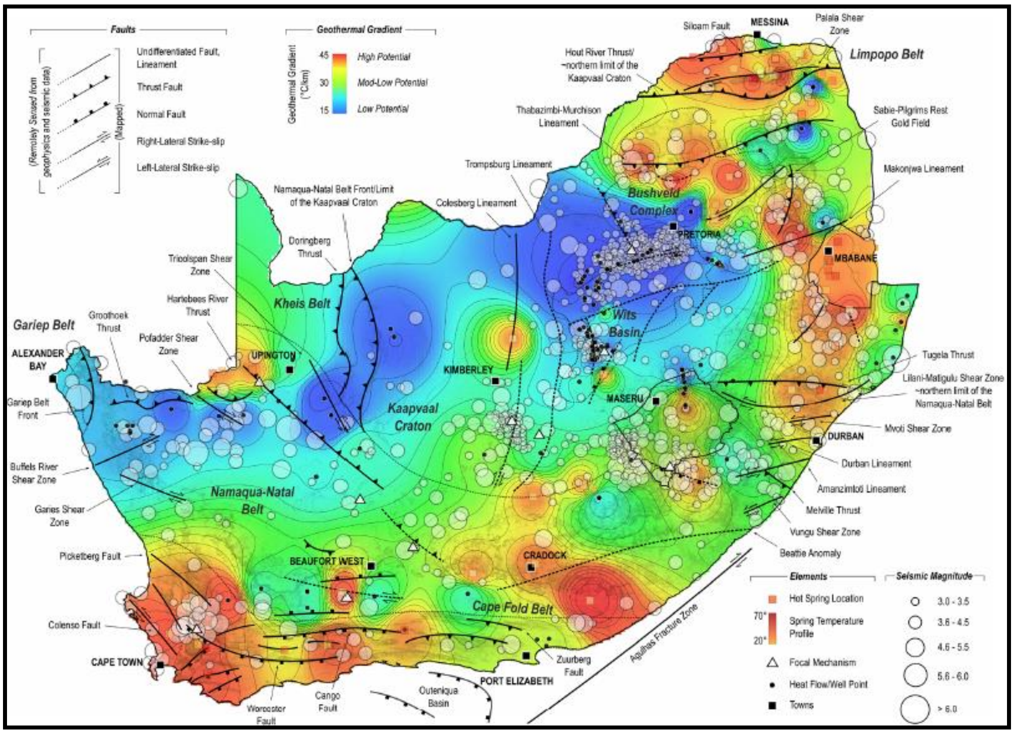

Figure 2: Graphical Overview of the Calculated Geothermal Gradients Across South Africa. (Map Includes Major Tectonic Contacts and Structures, Seismic Activity and Earthquake Focal Mechanisms and Hot Spring Locations) [1].

"Low-enthalpy geothermal energy is becoming increasingly popular around the world. This popularity is largely because it requires geothermal gradients as low as ca 40 °C/km, which may be found in many global settings. South Africa does not have any active or recent volcanism and is situated far from any active continental and/or oceanic plate boundaries but does have anomalously high heat flow regions that could meet the requirements for low-enthalpy geothermal energy development. Low-enthalpy resources are usually associated with ancient tectonic activity and are often defined by plutonic rocks with high concentrations of heat-producing radiogenic elements (e.g., uranium and potassium)

which are overlain by a thick and insulating volcano/sedimentary sequence." [1]

Conventional geothermal energy generation where the heat source must be accessed a few kilometres below ground is costly compared to geothermal heat sink requirements. Using the ground as a heat sink relies on the fact that the ground temperature beyond the seasonal layer (8 m) is at a stable temperature.

Geothermal heat sink technology uses the stable ground temperature as a heat exchange medium to cool the hot water exiting the condenser of a chiller. The heat sink technology consists of high-density polyethylene (HDPE) piping installed below ground in loops, arranged either horizontally or vertically in order for heat exchange from the fluid flowing through the HDPE piping to be transferred to the surrounding soil below the seasonal layer at 8 m – 10 m below the surface of the ground. The flow rate of the fluid within the HDPE piping is achieved via the hydraulic design of the heat sink loops and a mechanical pump with control system to vary the flow rate based on the heat rejection requirement. Fig. 3 shows the geothermal heat sink loop set-up with an existing chiller which is the typical arrangement anticipated with the adoption of geothermal heat sink loops at CTIA.

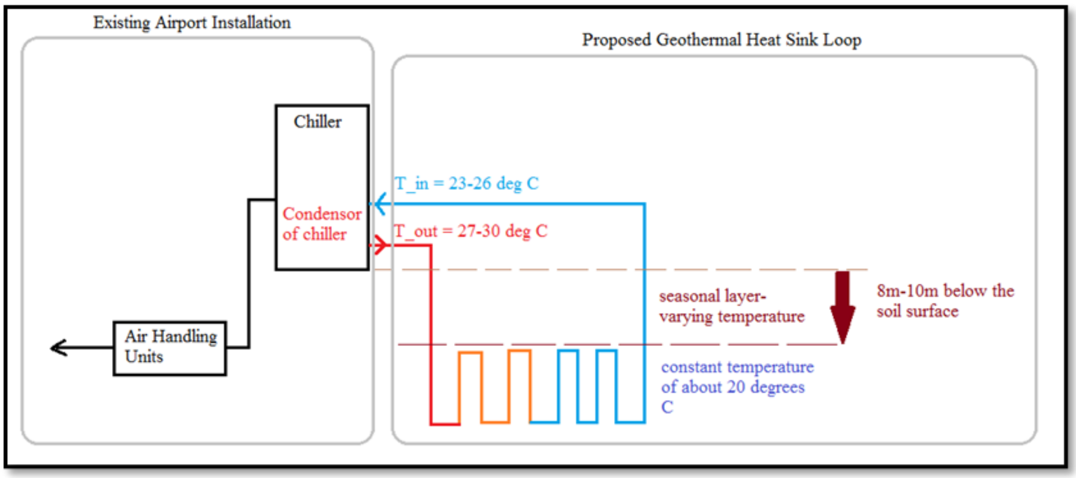

Figure 3: Geothermal Heat Sink Loop with Existing Chiller Set-up.

A difference in temperature of about 4 °C is required, as can be seen in Figure. 3. This ΔT of 4 °C is possible due to the ground temperature being at a stable temperature of 20 °C which is below the desired output temperature of a chiller's condenser at about 23°C. The ground heat exchanger loop arrangement depends on the space available, the space constraints (such as structural integrity), and convenience from a practical and cost perspective. Figure. 4 shows typical vertical and horizontal loop arrangements.

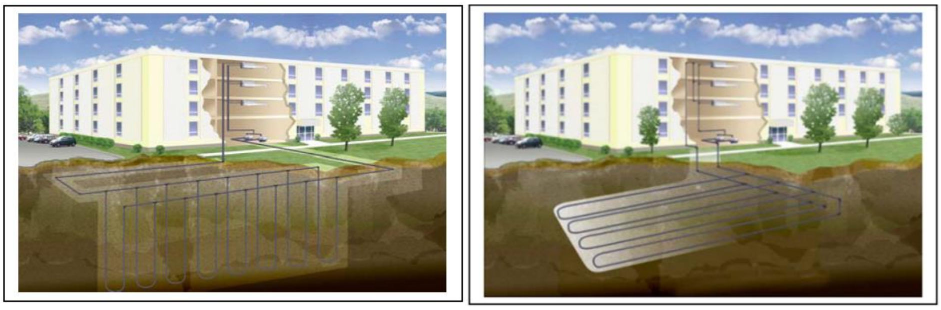

Figure 4: Vertical Loop (Left) and Horizontal Loop (Right) [2].

Vertical loops run perpendicular to the surface and can be buried several hundred feet deep. At these depths, the undisturbed ground temperature does not change throughout the year. Vertical loops require approximately 6.5 m^2/kW to 8 m^2/kW (250 to 300 ft^2/ton) of refrigeration [2]. A horizontal loop runs piping parallel and close to the surface. The undisturbed ground temperature often changes seasonally depending upon where the loops are installed. Horizontal loops are easier to install but require significantly more area than other loop types, approximately 65 m^2/kW (2500 ft^2/ton refrigeration) [2]. The geothermal heat exchanger loops are covered in grout which is a mixture of bentonite [2] and other elements such as quartzite, iron ore, cement mortar, and fly ash intended to protect the ground water in case of leaks but has minimal effects on thermal conductivity.

The installed technology involves designing a heat exchanger using HDPE piping with the ground functioning as the heat exchange medium. Each design will have a specific control programme as this is crucial for achieving the desired temperature change across the heat exchanger pipes. Therefore, it is important to study the ground temperature profiles carefully and design a programme that can respond dynamically.

3. ASSESSMENT OF TECHNOLOGY MATURITY

Geothermal energy use is not a new concept, and neither is its technology. The installed geothermal from 1990 to 2019 can be seen in Figure. 5. It is evident from the figure that this technology is particularly popular in the northern hemisphere, due to the cold winters in those regions. Geothermal energy can be used to heat homes in winter as well as provide for other energy needs.

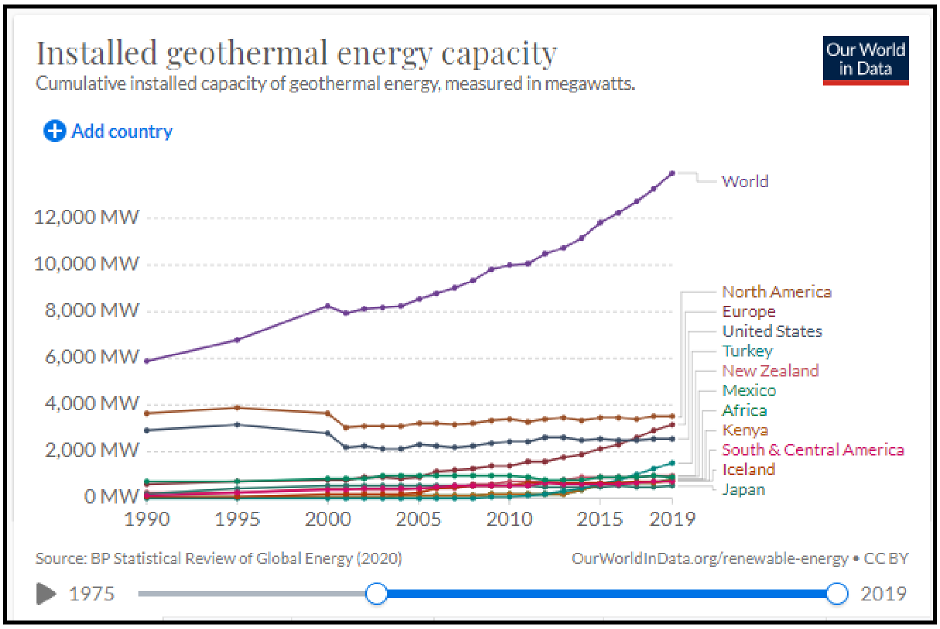

Figure 5: Installed Geothermal Energy Capacity from 1990 to 2019 [3].

According to the United States Department of Energy's website, about 50 000 geothermal heat pumps are installed in the United States of America each year [4]. Geothermal usage is low in the ranking of renewable energy technologies, but the uptake in the world is increasing at a fast rate (Figure.6) [5].

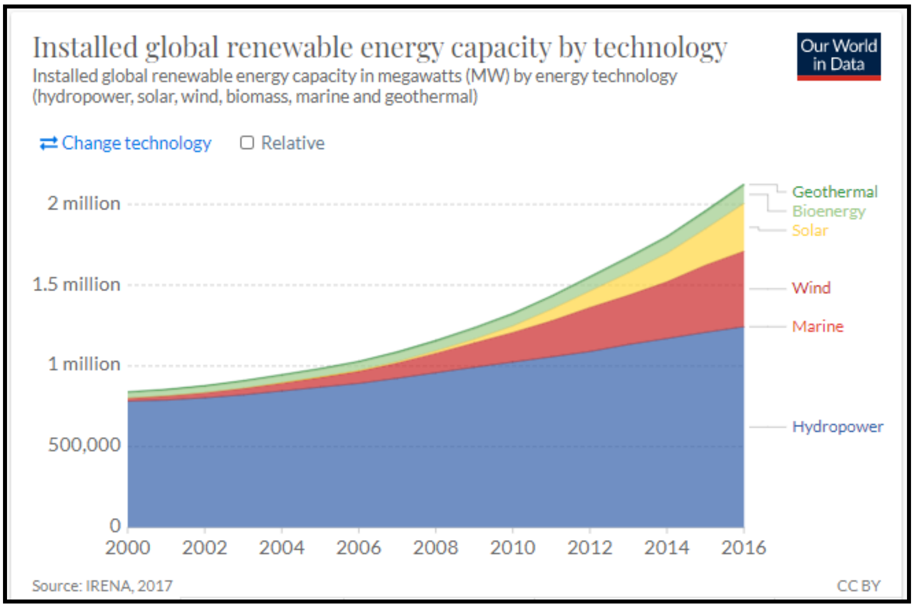

Figure 6: Geothermal Energy use in Relation to other Renewables in the Energy Space [5].

In South Africa, aside from Hotel Verde's installation, there is only one other geothermal system installed, an 18 borehole closed-loop geothermal heat pump system at the private residence of South African billionaire Douw Steyn. This is located in Steyn City, Johannesburg, and was installed by local environmental contracting company Environmental Drilling & Remediation Services (EDRS) [5].

4. COST-BENEFIT ANALYSIS

This technoeconomic assessment is a desktop exercise meant to provide an indication of the economics and suitability of geothermal heat sinks for an airport at pre-feasibility (FEL 2 or Front-End Loading Stage 2). The airport targeted for utilising a heat sink has been limited to CTIA due to the Hotel Verde installation about 2 km from the airport's terminal building. This section summarises the rationale for the scale of the geothermal heat sink technology at CTIA and presents the cost benefit analysis at pre-feasibility.

(a) Rationale for the Scale of Geothermal Heat Sink

Geothermal heat sinks are possible at all the nine geographical locations where the airports owned and operated by ACSA. However, to establish the depth at which the non-seasonal layer begins as well as develop a temperature profile of the ground at various depths, soil conditions, etc., a study must be conducted at each of the site locations. Hotel Verde is located in about 2km from CTIA and has successfully implemented geothermal heat sinks at 8 m depth. This indicates that there is a high likelihood of this technology working for CTIA provided that there is space available for the installation.

Due to the rarity of geothermal heat sink installations in South Africa, it was decided that the scale and cost of the Hotel Verde geothermal installation should be adopted for investigation at CTIA. A geothermal loop is intended to serve as a heat sink for the cooling towers, and the initial installation will have additional control and measurement devices to determine heat transfer coefficients, temperature difference, flow regimes and cyclic nature of the heat sink. This will serve as information for future ACSA installations across other airports.

Table 1 shows the various cooling towers at CTIA with the aim of selecting one that is closest to the heat rejection of Hotel Verde's installation for the purposes of replacement. The flow rate and fan capacities were taken from the data sheets of the cooling towers. The pump capacity was assumed to be 1 % of the cooling duty which is the case with most cooling towers, and the kW cooling required was calculated using the equation (1):

$$Q_{heat rejection} = mC_p\Delta T \quad \text{Equation (1)}$$

Where: m is the mass flow rate in kg/s which is the flow rate in table 2 multiplied by 1000

C_p is the specific heat capacity of water at constant pressure = 4.19 J/kgK

ΔT is the change in temperature in Kelvin (K) and is taken at 2.5 K

The cooling tower heat rejection that best matched the Hotel Verde scale at CTIA was cooling tower 1 in terminal 5, as highlighted in Table 1. Hotel Verde's full HVAC system consists of an integrated heat pump system providing the hot water needs of the hotel as well as the HVAC requirements, and cost ZAR 26 600 000 [4]. The heat rejection which is accomplished via the geothermal loop is around 305 kW, consisting of 100 boreholes drilled to a depth of 65 m each and 13 km of HDPE piping. The 2018 cost of the system is shown in Table 2.

Table 1: Cape Town International Airport Cooling Towers Specifications

CTIA Cooling Towers	Flow Rate (m^3/s)	Total Cooling Required (kW)	Fan Capacity (kW)	Pump Capacity (kW) – Approximated to be about 1 % of the Total kW Cooling
Terminal 5: Cooling Tower 1	0.039	408.525	22	4.1
Terminal 5: Cooling Tower 2	0.039	408.525	22	4.1
Terminal 1: Cooling Tower 1	0.042	439.95	30	4.4
Terminal 1: Cooling Tower 2	0.042	439.95	44	4.4
CTB: Cooling Tower 1	0.083	869.425	11	8.7
CTB: Cooling Tower 2	0.083	869.425	11	8.7
CTB: Cooling Tower 3	0.083	869.425	11	8.7
CTB: Cooling Tower 4	0.083	869.425	11	8.7
CTB: Cooling Tower 5	0.083	869.425	11	8.7
Total Cooling (kW)		6044.075	173	47.87075

Table 2: Approximate Cost of Hotel Verde's Geothermal Heat Sink System in 2018

Item	Cost in South African Rands ZAR (2018 basis)	Cost Detail and Notes
Boreholes, piping	4 104 810.00	• 100 boreholes at ZAR 41 000 per borehole of 65 m deep (estimated 2018 price from a previous project done at KSIA on the feasibility study of borehole water use). • 13 km of HDPE Piping at ZAR 370 per km (estimated 2018 price from online sales).
Instrumentation	205 240.50	• Estimated at 5 % of the cost of total cost of drilling the boreholes (include cost of control and instrumentation to monitor the operations of the installation).
Design and labour; balance of plant (BoP)	820 962.00	• Estimated at 20 % of the total cost of drilling the boreholes (typical figures used for design and labour and extra allowance is made for BoP).
Total	5 131 012.50	• This total cost agrees with the cost as per the United States (US) geothermal installations.

The above total cost of ZAR 5 131 012.50 was used as the 2018 cost basis upon which it was benchmarked according to the US geothermal installed systems.

(b) Feasibility Study Results

Airports Company South Africa has an economic modelling department that creates economic models in excel spreadsheets. The economic model yields the Net Present Value (NPV), internal rate of return (IRR), the nominal payback period and the profitability index. The IRR is compared to ACSA's 11.5 % weighted average cost of capital (WACC) rate (2018) to determine economic feasibility. When the NPV is zero or positive is it an investment that pays itself off during its economic lifespan. The NPV equation used in the economic model is given below (Equation 2), the IRR is the return (*i* in below equation) when the NPV is zero. When the IRR is greater than the discount rate (or the WACC rate), then the investment is feasible for the business. The payback period is the amount of time required for cash inflows generated by a project to offset its initial cash outflow. The payback should be reasonably within the economic lifespan of the investment. The profitability index (PI) (given in Equation 3) shows the financial attractiveness of the proposed project and is the ratio of the sum of the present value of the future expected cash flows to the initial investment amount. A PI greater than 1.0 is deemed to be a good investment, with higher values corresponding to more attractive projects.

$$NPV = \sum_{t=0}^{T} \frac{R_t}{(1+i)^t} \qquad \text{Equation (2)}$$

Where: $R_t =$ net cash inflows – outflows during a single period *t*

- *i* = discount rate or return that could be earned
- *t* = number of time periods

$$PI = \frac{PV\ of\ future\ cash\ flows}{Initial\ Investment} \qquad \text{Equation (3)}$$

The resulting replication of the Hotel Verde geothermal heat sink loop gives an end of job (EoJ) cost of ZAR 5.67m and a NPV of ZAR 2.51m at an IRR of 18.1%. The inputs used in the economic modelling and the financial outputs can be seen in Table 3. Further description of the data used in the economic models and the source of the information is

provided in Table 4.

Table 3: Summarised economic analysis

Inputs		Output	
kW heat rejection	305 kW	End of job cost	ZAR 5.67m
Capital cost (2018 basis)	ZAR 5 131 012.50	Net present value	ZAR 2.51m
Water saving	9.12 kL/day	Internal rate of return	18.1 %
Water cost	ZAR 88.75 /kL	Annual operational cost saving	ZAR 463 382.91
Electricity saving	114 253 kWh/annum	Nominal payback period	6 years
Electricity cost (2018 basis)	ZAR 1.47 /kWh	Profitability index	1.55
Beneficial operation	2021		
Construction period	1 year		
Corporate tax	28 %		
Economic lifespan	20 years		
Degradation	0.5 % per annum		
Operational and maintenance cost	ZAR 12 000 /annum (2018 terms)		

Table 4: Base Case Description

Base case Descriptor	Base case Parameter/Result	Base Case Sources and Assumptions
Airport for implementation	Cape Town International Airport	Due to the Hotel Verde's proven implementation within a 1 km radius from CTIA
Size of plant	305 kW heat rejection	Duplication of Hotel Verde's geothermal heat sink loop
Annual electricity saving	114 253 kWh	Based on the fan and pump electricity savings running for 12 hours a day, 365 days a year; Hotel Verde's system achieves fluid circulation through a carefully designed hydraulic configuration where the water flows naturally
Annual water saving	9.12 kL/day	Based on actual cooling tower water consumption; blowdown losses accounted for using actual data
Capacity factor	N/A	The geothermal loop will be available all the time
Depth of boreholes	65 m	As per Hotel Verde's boreholes depth
Potential annual cost saving at full capacity	ZAR 463 383	Based on savings from electricity and water consumption
Annual maintenance cost	ZAR 12 000	Based on Hotel Verde's maintenance cost of R60 000 spend to repair a leak that developed after 5 years

This pre-feasibility study (FEL 2) conducted for CTIA by replicating the geothermal loop at Hotel Verde proves to be feasible. To determine the factors that this feasibility is most sensitive to, a sensitivity analysis was performed.

(c) Sensitivity Analysis

For the sensitivity analysis, the four factors that play a role in the determination of the profitability of the investment were varied equally to see the significance of impact each parameter had on the profitability of the project relative to each other.

The profitability of the investment relies on the capital cost of the installation (CAPEX), the cost of potable water, the cost of electricity from Eskom and the operational cost (OPEX) of the geothermal heat sink loop field. The effect that these four factors have on the NPV of the project can be seen in Figure 8.

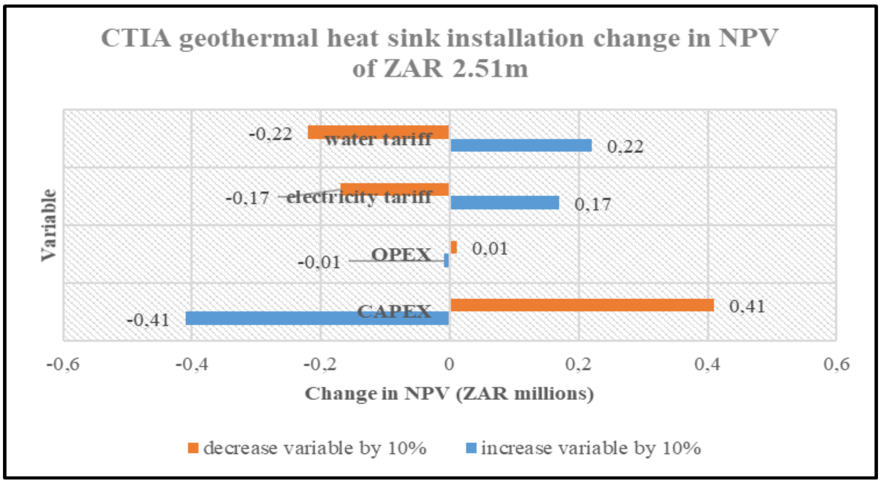

Figure 8: Sensitivity Analysis of the Replication of the Hotel Verde's Geothermal Loop at CTIA.

A 10 % increase and decrease in CAPEX, OPEX, electricity cost and water cost show that the capital cost is the most significant factor and the operational cost the least significant factor. The variation in water tariff has about 50 % of the impact that the variation in capital cost has on the NPV. Following closely on the impact of the water tariff is the impact of the electricity tariff. This sensitivity analysis implies that water consumption savings are key to the business case for geothermal heat sinks.

If it is known that any of the other airports are experiencing a drought condition and the cost of water is approaching or exceeded ZAR 88,75 /kL, this technology should be considered for implementation instead of using cooling towers.

5. TECHNOLOGY RISK ASSESSMENT

The technology (piping, pumps, etc.) that use the ground as a heat sink have all been in existence for longer than the concept of utilising it for geothermal energy. The HDPE pipework in geothermal ground heat exchange is used in plumbing applications, and pumps and controls have been in existence for longer than 50 years. Heat exchanger designs in air conditioning, engines and other applications were being used before the advent of geothermal applications as well. The unique factor to be considered in ground heat exchanger design need are ground temperature and its fluctuations, hence the control system real time response is crucial. The technology risk assessment in this context is provided in Table 5.

Table 5: Technology Risk Assessment

Risk	Description	Possible Mitigation
Ground temperature and fluid temperature to be cooled being equal	As in any heat exchanger design, heat naturally flows from a hot reservoir to a cold reservoir; it is this difference in temperature that causes heat exchange. Should the temperature difference cease, there will be no further heat exchange until a temperature difference exists.	*1.* Designing of the loop field must model scenarios of possible ground temperature change due to the added heat load of the building and ensure that the system is designed to minimise/eliminate the possibility of a temperature equalisation. *2.* The design should incorporate an alternative method of achieving the heat sink such as bypassing the geothermal loop for another cooling tower or using another chiller to carry the heat load especially for the first installation until a temperature gradient is restored.

Single point of failure	This is failure at a single point which without, the entire plant will not be able to operate. This includes loss of pressure (mechanically) or loss of control system (software, hardware or communications).	*3.* Modularity should be introduced so that should a failure occur in one loop, it can be isolated and the rest of the loops can carry the load while the failed loop is being repaired. *4.* Control systems must be employed to ensure that this transition is smooth and there is no impact on HVAC operations. *5.* Active monitoring and early detection of failure should be incorporated. A fail-safe mode or default mode should be programmed/hard-wired into the system in case of operational loss of the control system.
Agility	This is the ability of the plant's operational output to respond to varying demand timeously without causing operational impacts or damage to infrastructure.	*6.* During design, dynamic varying of fluid flow rates should be programmed based on the ground temperature, fluid temperature, required heat rejection and alternative heat sink/s or back up plans should be incorporated in case of reduced heat exchange.
Turn-down ratio	This is the ability of the plant design capacity to be increased and decreased in capacity to suit operational need and maintenance regimes towards cost effectiveness.	*7.* Understand the demand profile of the airport's air conditioning load, the corresponding heat sink requirements, ground temperature profiles and adjusted temperature profiles of the ground during operation of the geothermal loop to build in modularity towards cost effectiveness for operations and maintenance.

6. AIRPORT'S INTEGRATION STRATEGY

The consideration of geothermal heat sinks for CTIA must be in relation to the airports HVAC refurbishment and replacement programmes should be adopted for a cost-effective integration strategy. CTIA's integration strategy should be such that the first installation is completed as a replication of Hotel Verde's installation. Monitoring and analysis of flow regimes should then follow to generate accurate design data for further installations. Roll out of the geothermal heat sink loop should then follow. Refer to the schematic in Figure. 9. The three phases as per the airport's integration is described following Figure. 9.

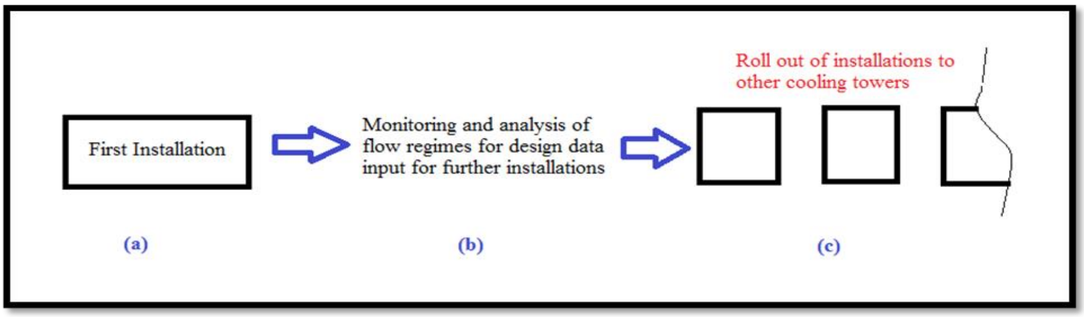

Figure 9: Phases of Integration of the Geothermal Heat Sink Technology Replacing Evaporative Cooling Towers at CTIA.

The following sections describe the phases of integration of the geothermal heat sink installation at CTIA in time replacing all the evaporative cooling towers at the airport.

(a) Replication of Hotel Verde's Geothermal Loop

The integration of the geothermal heat sink loop into CTIA's HVAC system should be such that the first geothermal heat

sink loop installation is done to replace the evaporative cooling tower that meets the following criteria:

- Due or soon due for replacement/refurbishment and a low book value
- Has adequate land area for either a vertical or horizontal geothermal heat sink loop
- Can be easily integrated without inconvenience that will either pose unacceptable operational risks or result in capital integration costs that will result in a negative IRR.

The FEL 3 (final feasibility) stage should include further investigation that may require funding for services to perform detailed investigations that will confirm the financial viability of the installation based on the prevailing soil and spatial conditions at CTIA. Table 6 gives the scope and indicative cost of the professional services required to confirm feasibility at FEL 3 of a geothermal heat sink installation at CTIA.

Table 6: Cost to Confirm Feasibility for an Investment Decision (FEL 3 Stage)

	Task	Duration (hours)	Estimated cost (ZAR) (2019 basis)
1	**Integration parameters of geothermal at CTIA**	**32**	**67 584**
	• Capital cost of integration, pipework, controls and instrumentation, modifications and other integration requirements	24	50 688
	• Confirmation of scale and design parameters of geothermal heat sink loop as per Hotel Verde's design and qualify suitability for implementation at CTIA	4	8 448
	• Operational cost of the geothermal field	4	8 448
2	**Plant scale and operational parameters to mitigate risk. Requirements are:**	**128**	**270 336**
	• Investigation into the ground temperature profiles and proposal of the possible geothermal heat sink loop sites for full roll out	16	33 792
	• Investigation into airport's heat sink load profiles in totality and specific to each cooling tower in conjunction with ground temperature profiles to establish flow regimes, control methodology and integration into airport's current HVAC system	24	50 688
	• Investigate environmental obligations and provide scope, timeline and costing	8	16 896
	• Identify risks, mitigations and investigate the cost of risk	8	16 896
	• Provide condition assessment of cooling towers and advise on cost effective roll-out strategy	24	50 688
	• Plant footprint, identification of plant location, spatial and legal requirements and associated costs	36	76 032
	• Single point of failure analysis, cost to restore, mitigations and cost of mitigation	12	25 344
3	**Feasibility and implementation**	**48**	**101 376**
	• Total cost of installation	8	16 896
	• Owner’s cost	8	16 896
	• Feasibility of the investment and sensitivities	8	16 896
	• Project timelines, milestones	4	8 448
	• Procurement strategy for installation, operations and maintenance	8	16 896
	• Basic design that will inform detailed design	12	25 344
4	**Other costs**		**65 894**
	Travel, preliminaries and general		21 965
	Monitoring, data collection, simulation		43 930
	Contingency	10 %	50 519
	TOTAL	**208**	**555 709**

(b) Monitoring, Collection of Data and Analysis

Once the first installation is complete, continuous monitoring and analysis of the various heat flow cycles, flow rates and response of the systems should be done to enable the next design to easily determine the following parameters as contained

in Equation (4): [2]

$$Q_c = \frac{L(T_g - T_w)}{R} \qquad \text{Equation (4)}$$

Where: Q_c is the heat load (Btu/hr)

L is the pipe length (feet)

T_g is the ground temperature

T_w is the fluid temperature

R is the thermal resistance to heat transfer.

The challenge in loop design is that the ground temperature does not stay constant, the loop itself affects the ground temperature. For loop design, it is common to break the effects into three parts: [2]

- **Long Term Effect -** This is the change in the ground temperature over many years. If the building has a net heat gain or a net heat loss, the ground temperature will change. The more densely placed the boreholes are, the larger this effect will be. Ground water moving through the bore hole field can help remove energy and limit the long-term temperature change. For commercial applications, ground temperature generally climbs. An example of a long-term effect would be a 6 °C average ground temperature increases over 10 years due to the heat added to the borehole field. The penalty will not be present during the first year, but this type of heat build-up will change the system performance over time [2].
- **Annual Effect -** Over the course of a year, the heat load on a bore field will change and this will affect the ground temperature on a monthly basis. It is this "flywheel" effect that can cause the warmest ground loop temperature to occur after the peak load has occurred [2].
- **Short Term Effect -** The actual load on the loop will affect the fluid supply temperature. For example, if the building was shut down, the fluid temperature would quickly become the ground temperature. However, the loop temperature would be the ground temperature plus the design approach at design load. The actual hourly load also affects the borehole field's ability to dissipate heat. Therefore, the ground temperature will change with the hourly load. Most loop sizing software group the design day loads into four-hour intervals rather than using all 24 hours [2].

These three effects must be known to find the required pipe length. The length suitable for CTIA may be established by the summer heat sink load requirement. The summer peaking load establishes the length, and the designer should go back and evaluate the cooling performance with the longer length. This will improve the summer performance and minimise the need for back-up cooling towers. Understanding the ground temperature profile, the airport's heat sink requirements and the loop temperature response for the geothermal heat sink zone is key for effective design.

(c) CTIA's Full Roll out of Geothermal Heat Sink Loops

The establishment of a better understanding of the designing of heat sink loops based on the first installation will be the basis for further roll-out at CTIA. The roll-out should be timed with the replacement cycles of the existing evaporative

cooling towers, however, back-up cooling towers should be available to serve the fluctuating heat rejection load (i.e., excluding the baseload) limited to 25 % of maximum heat rejection load or as per the most economical ratio for back-up cooling towers. The potential of the full roll-out of the geothermal heat sink loops is provided in Table 7.

Table 7: Summary of Benefits of the Geothermal Heat Sink Technology for CTIA

CTIA Cooling Towers Replacement with Replication of Hotel Verde's Geothermal Heat Sink Loop	Potential Annual Energy Saving (kWh)	Potential Annual Water Saving (kL)	Potential Annual Operational Cost Saving (ZAR) (Excluding Maintenance Cost Savings)	Potential Annual Carbon Footprint offset (%) from Electricity Savings only
Terminal 5: Cooling Tower 1 replaced with 1 x Hotel Verde's geothermal loop	114 253 kW	3 328 kL	ZAR 463 383	0.17 %
Terminal 5: Cooling Tower 2 replaced with 1 x Hotel Verde's geothermal loop	114 253 kWh	3 328 kL	ZAR 463 383	0.17 %
Terminal 1: Cooling Tower 1 replaced with 1 x Hotel Verde's geothermal loop	114 253 kWh	3 328 kL	ZAR 463 383	0.17 %
CTB: Cooling Tower 1 replaced with 2 x Hotel Verde's geothermal loop	228 506 kWh	6 656 kL	ZAR 926 766	0.33 %
CTB: Cooling Tower 2 replaced with 2 x Hotel Verde's geothermal loop	228 506 kWh	6 656 kL	ZAR 926 766	0.33 %
CTB: Cooling Tower 3 replaced with 2 x Hotel Verde's geothermal loop	228 506 kWh	6 656 kL	ZAR 926 766	0.33 %
Total	**1 028 277 kWh**	**29 952 kL**	**ZAR 4 170 447**	**1.5 %**

7. PROPOSED OPERATIONAL PHILOSOPHY

(a) Technical

The phase of integration that involves the replication of Hotel Verde's geothermal heat sink loop will be from terminal 5 as seen in Figure. 10 below.

- The geothermal heat sink loop will take most of the operational load with peak loads being shared with a cooling tower. It is advisable to keep the cooling tower that is in a better condition and replace the second cooling tower with the geothermal heat sink loop the size of Hotel Verde's installation.
- The geothermal heat sink loop itself should be divided into two ground heat exchange zones such that when the ground temperature and the fluid temperature are equalised and further heat exchange is required, the second zone should be able to carry the load.
- The geothermal loops should be designed for ease of isolation and maintenance purposes without compromising the functionality of the rest of the geothermal heat sink loop field.
- As far as possible, pumping head and flow rate should be minimised making using of hydraulic design, Bernoulli's equation and Pascal's Law.

The monitoring, collection of data and analysis thereof should carefully consider the outputs required for efficient

designs that could be used for further roll-out. Monitoring for establishment of suitable flow regimes, length and depth of geothermal loops, grout types and pumping capacities will be key inputs into further designs. The heat sink load profile during the summer period, ground temperature profile effects and flow regimes are crucial for this phase to fine tune the replicated geothermal loop and as input into further designs. It is advised that this phase be timed such that it considers the summer heat sink loads.

The final rollout phase should seek to achieve the set-up described in Figure. 10. The geothermal heat sink loop fields should be sized to serve the operational baseload and peak loads should load share with standby cooling towers as well to ensure that the heat sink loop has sufficient time to recover in order to maintain a temperature gradient.

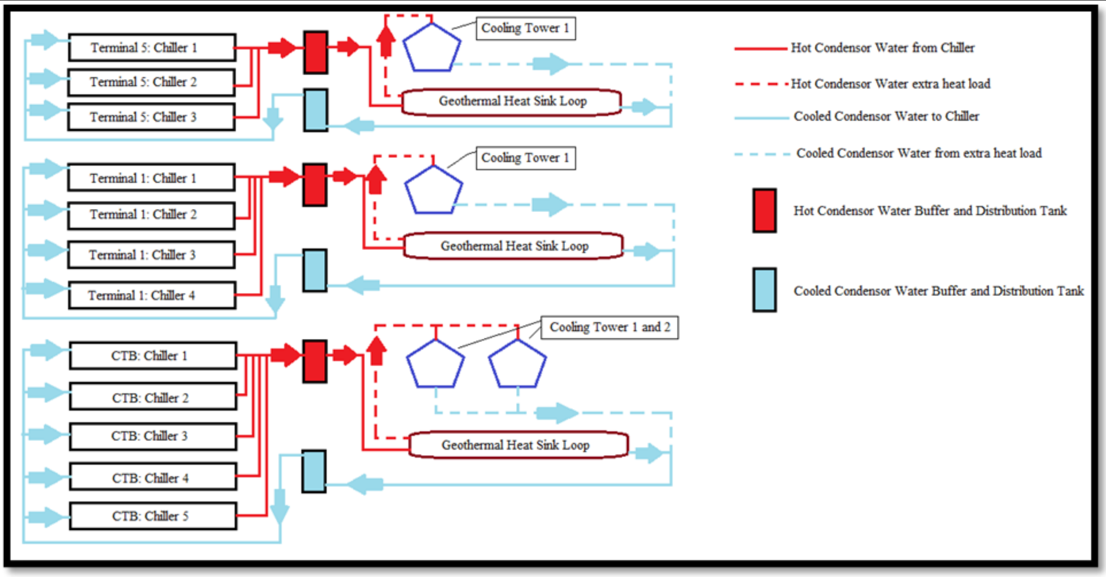

Figure 10: Full Roll out of Geothermal Heat Sink Loops at CTIA.

(b) Plant Operation for Business Continuity and Cost Effectiveness

The geothermal loop heat sink cooling duty and the cooling towers heat sink cooling duties should consider the following:

- Baseload and fluctuating load in the heat sink load profile
- Time for the geothermal heat sink zone's temperature to equalise to the temperature flowing within the loop
- Economies of scale

Using the above information, the geothermal heat sink zones should be spaced accordingly such that the heat load profile can be met. The capacity of heat sink loads placed on cooling towers should consider the minimum cooling requirement in the case of a total loss of the geothermal loop field.

(c) Operations and Maintenance Activities

Operations of the geothermal loop field is to be electronically programmed and run independently of human input. There should be a default mode should the system parameters received from the control system that are used in real time feedback control not be within pre-defined parameter bounds. Pressure loss or any other failure should be linked to a maintenance alert system which will switch the system to a fail-safe mode of operation.

Maintenance will need to be contracted out for the first installation as this is not a skill found within ACSA. Breakdown maintenance should be on a call-out basis and is likely to be mainly due to heat sink loop leaks. Preventative maintenance should be based on the condition of the geothermal loop. The system usually runs as per the electronic control programme and requires no human intervention, except for maintenance.

8. CONCLUSIONS

The use of geothermal energy is not a new concept and is frequently used in the northern hemisphere for heating and cooling purposes. The technology is also well known, however, its use in South Africa is not as common as solar photovoltaic technology. Geothermal energy technology works for Hotel Verde in the Western Cape of South Africa, located within a kilometre of the CTIA. It is for this reason that the technology will work for CTIA. The feasibility study (FEL 2) conducted for the installation at CTIA proves that it is financially feasible. At FEL 2 (pre-feasibility stage), geothermal energy has the potential to save ZAR 4.1m per annum and the potential to reduce carbon footprint by 1.5 %. This will be instrumental in transitioning CTIA toward a lower carbon footprint, enabling progress towards the airport's green star rating with the Green Building Council of South Africa as well as the Airports Council International (ACI) carbon accreditation.

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